Scour Mechanics of Aggregate Obstacle Fields with Application to Mine Countermeasures

Douglas L. Inman
Center for Coastal Studies
Scripps Institution of Oceanography, UCSD
La Jolla, CA 92093-0209
phone: (619) 534-4334 fax: (619) 534-0300 email: dli@coast.ucsd.edu

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Scott A. Jenkins
Center for Coastal Studies
Scripps Institution of Oceanography, UCSD
La Jolla, CA 92093-0209
phone: (619) 534-6480 fax: (619) 534-0300 email: saj@coast.ucsd.edu

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LONG-TERM GOAL

We seek to understand the leading order processes and develop quantitative modeling skill for the problem of scour and burial of solid objects on a sedimentary bed in geophysical flows.

OBJECTIVES

(1) Identify leading order processes; (2) formulate the model and write the computer code; (3) establish a database with seasonal and climatic variability of wave forcing and sediment budget inputs to initialize and calibrate the model; (4) validate the model in a contemporary field experiment with modern mines of various shapes; (5) determine the relative strength of various scour and burial mechanisms and the sensitivity of those mechanisms to the fluid forcing history and episodic sediment fluxes; and, (6) exploit the results of the field and numerical experiments to pose potential mine countermeasures.

APPROACH

There are two mechanisms in our formulation of the mine scour and burial problem: (1) a near-field burial mechanism involving sediment transport by the vortices shed from the mine shape, and (2) a far-field burial and exposure mechanism that involves the net accretion or erosion of the near-field by far-field sources and sinks. Initially the near-field mechanism leads only to scour and eventually to burial in the absence of far-field activity. However, once an object is buried, re-exposure requires far-field change. Both near- and far-field mechanisms apply to either wave dominated or current dominated regimes, and to combined wave-current regimes. Hence this model applies to objects on wave dominated nearshore bottoms, and to objects on current dominated beds in rivers and estuaries. Separation of the model architecture into far-field and near-field burial mechanics permit the model to be adaptable to geophysically or geotechnically diverse coastal settings while accounting for seasonal and climatic variability (Inman et al. 1996).

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The near-field burial mechanism has been posed in terms of scour transport induced by the local vortex system shed from the mine shape (Inman and Jenkins, 1996). The vortex system has been formulated using the vortex lattice method. The vortex lattice prescribes a system of trailing vortex filaments over the sedimentary bed. Each vortex filament produces scour by two distinct transport processes, bedload and suspended load transport. The down-washing induced by the trailing vortex filaments produces a flow convergence on the seabed, which elevates the bottom stress above the threshold of motion for the ambient sediments. The tangential velocity induced by the trailing vortex filaments causes bedload induced scour transversely across the wake proportional to the cube of the circulation generated by the bluff-body shape of the mine. Finally, the up-wash induced along the wake perimeter by the vortex filaments gives rise to scour resulting from the flux of seabed material into suspended load, a mechanism that is proportional to the fourth power of the bluff-body circulation. (Jenkins & Inman, submitted).

When applied to rivers and estuaries, the far-field burial mechanism utilizes sediment rating curves based on river flow rates (Figure 1) to determine river sediment flux and deposition fluxes in the sediment budget (Figure 2). Initially, the interdecadal variability of large episodic river sediment fluxes is quantified using the Hurst Rule (Hurst, 1951).

When applied to wave dominated shelf environments, the far-field mechanism is treated as a class of thermodynamic system, (Figure 3), involving the isothermal dissipation of external work (by incident waves and currents) into heat of external reservoirs (heat of vaporization into sea spray and conduction of latent heat beyond closure depth). This class of thermodynamic system achieves equilibrium bottom profiles in accordance with the 2nd law of thermodynamics by seeking states of minimum internal energy, i.e., potential energy in the pressure field and kinetic energy in the velocity field (Jenkins & Inman, in press). Consequently, the nearshore profile achieves equilibrium by maximizing the rate of dissipation of work performed by the mean current and wave-induced stresses. The rate of working performed by mean stresses is assigned to two distinctly different mechanisms, each dominating in separate portions of the cross-shore, with an outer region (the shorerise) and an inner region (the bar-berm) (Inman et al. 1993). The equilibrium profile changes from one equilibrium state to the next as a transient condition known as a ***stationary state*** (i.e., slowly varying). The stationary state solution for transitional bottom profiles is posed by the principle of minimum entropy production, which requires the maximization dissipative work by the time varying bottom stresses, Jenkins & Inman (in press).

WORK COMPLETED

Progress has been made on all six objectives during FY-98 and during the antecedent bridging period of funding for this two year effort. Four peer-reviewed papers, two conference proceedings papers three AGU abstracts, and one database report resulted from the FY-98 research.

RESULTS

We have learned that the near-field burial processes in wave dominated shelf environments are relatively slow and can be retarded further by the presence of coarse aggregate collecting in the local scour features (Inman & Jenkins, 1996). Surprisingly, two years of monitoring our MANTA mine installation has revealed that the far-field mechanism is the dominant and most dynamic burial mechanism, at least on a collision coastline such as California. We have found that the local vortex scour is a second order

burial process relative to the large scale deposition or erosion of the ambient seabed. To resolve the far-field burial mechanism requires detailed sediment budget inputs over length scales of littoral cells and geomorphic provinces, and spanning temporal periods of interdecadal scales. The Hurst Rule analysis of the flow and sediment flux of the 20 largest streams draining the coast of central and southern California delineated the effects of decadal scale climate changes in general agreement with the Pacific/North American (PNA) climate pattern (Inman & Jenkins, submitted), yielding a dry climate extending from 1944 to about 1968 and a wet climate extending from 1969 to the present (Zhang et al. 1997). The wet period involves flurries of strong El Niño events accompanied by severe storms and extensive runoff along the coast. Within the wet period, strong El Niño events with series of cluster storms occur every 3 to 7 years, and the average sediment flux due to the 3 largest of these events was 27 times greater than during the preceding dry period (Inman et al, 1998). The 1969 flood (Figure 1) which ended that dry period, was a first flush event for fine sediment in most of these river basins, and the proportion of fine sediment was significantly larger than in subsequent floods. Using the mine burial model to hindcast the effects such an event could have on mine warfare revealed that it probably would have rendered Italian Manta mines virtually undetectable if placed in the access channel to Alameda Naval Station (Figure 2), burying them in less than 100 days under a layer of new mud deposition nearly 4 times deeper than the height of the mines (4 x 40 cm = 160 cm).

In solving the thermodynamic problem for the equilibrium states of the far-field burial processes (Figure 3), it was found that both the shorerise and bar-berm profiles have the general solution, $h = Ax^m$, where h is the depth, and x is the cross-shore component taken as positive in the offshore direction, Jenkins and Inman (in press). The shorerise profile curvature exponent was found to be $m = 2/5$ for most nearshore conditions, but can fall as low as 0.24 for well-mixed high energy shelves. In the bar-berm region the curvature exponent was found to be $m = 2/5$, and the profile factor A was found to increase with increasing grain size. The solution for the transitional profile as a stationary state (slowly varying) was found to have a curvature exponent $m = 2/3$ in both the shorerise and bar-berm. These results correlated well with parametric analysis of 60 profile measurements from 4 different littoral settings (Inman et al, 1993).

IMPACT/APPLICATIONS

We believe our segregation of mine scour and burial between near-field processes (dominated by local vortex transport) and far-field processes (dominated by the variability of sediment erosion and deposition in the mine environment) has resulted in both a versatile model and a new insight into what the dominant burial and exposure processes may be. In studying the near-field vortex induced transport mechanics, we have discovered a potential mine countermeasure, involving seeding a mine field with coarse binary aggregate to retard the burial sequence and enhance the detectable footprint of the mine. But we have also learned that such a countermeasure works only if the mine environment remains constant. What is most significant about our findings is that they have identified the mine environment, and the variability of that environment as a set of parameters that are at least as important as the mine specifications itself. In particular we have identified and quantified interdecadal patterns in the set of environmental modeling parameters. We have also resolved a debate surrounding what the curvature of the equilibrium bottom profile should be. In doing so we have made the first application (to our knowledge) of thermodynamic laws and principles to coastal processes.

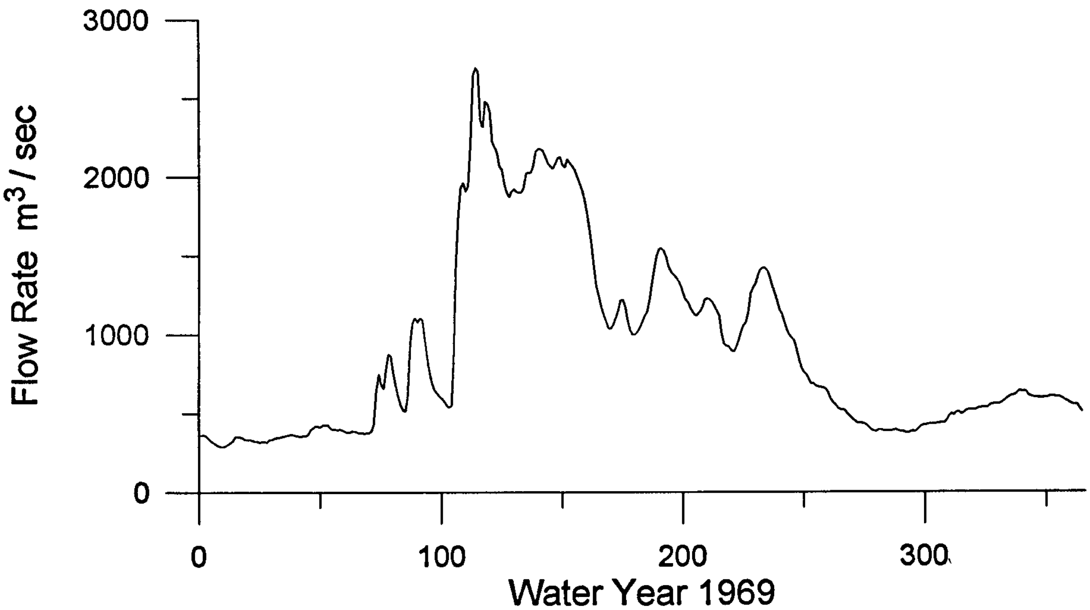

FIGURE 1: Daily Mean Flow Rate - Sacramento River, USGS Station #11447650

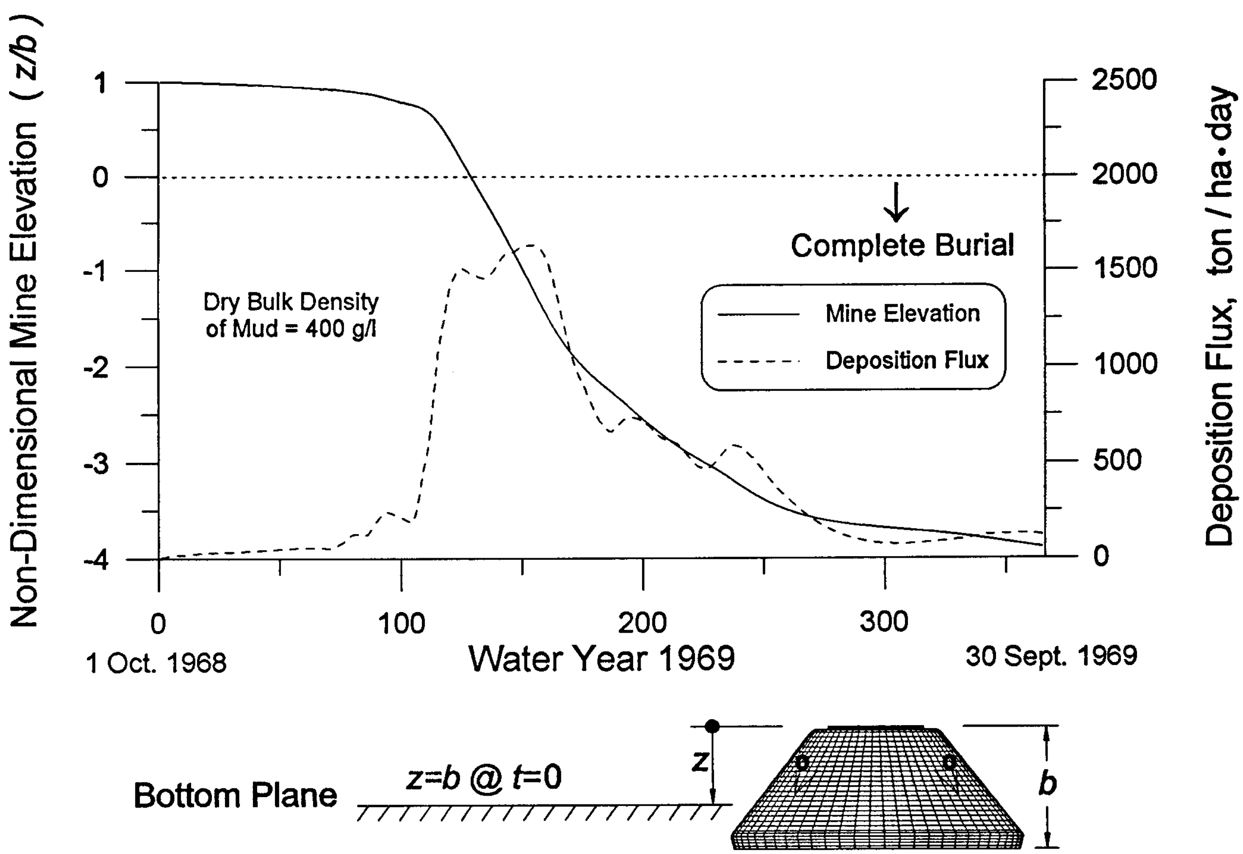

FIGURE 2: Deposition flux and mine elevation, navagation channel Alameda Naval Station

TRANSITIONS

The numerical architecture and FORTRAN codes developed under this grant have been used to calculate the transport of littoral sediments in a planned wetlands restoration at San Dieguito Lagoon, CA, to be built by the Southern California Edison Co. (Jenkins & Inman, submitted).

RELATED PROJECTS

We have had a number of exchanges of technical reports, letters, and conversations with Dr. Michael D. Richardson, who heads the Mine Burial Processes Program at the Naval Research Laboratory, Stennis Space Center, MS. Concepts for a joint experiment have been considered. In addition, we have interacted with the Naval Research and Development Laboratory, CODE 352, San Diego, and the Mobile Mine Assembly Group, Unit One, Seal Beach, who have provided us with inert mines for our field experiments.

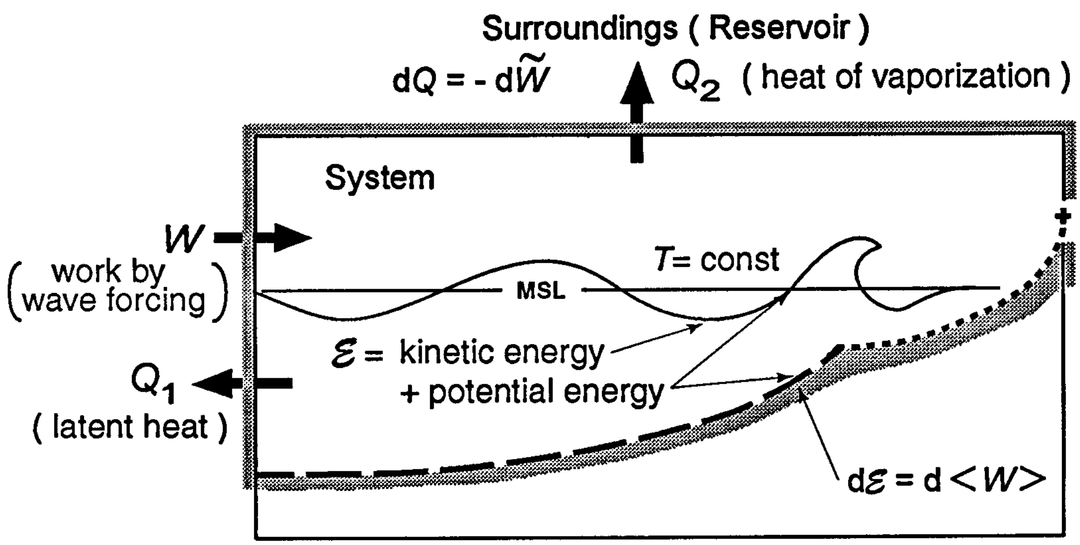

FIGURE 3: Thermodynamic formulation of the equilibrium profiles

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